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ORIGINAL ARTICLE

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Cardiovascular adaptations after 10 months of intense school-based physical training for 8- to 10-year-old children

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This study examined cardiovascular adaptations in 8- to 10-year-old schoolchildren after 10 months (a full school year) of 3 × 40 minute per week of small-sided ball games (SSG, including football, basketball, and/or floorball) or circuit strength training (CST). The study involved 291 Danish schoolchildren, 8-10 years old, cluster-randomized to SSG (n = 93, 4 schools, 5 classes), CST (n = 83, 4 schools, 4 classes), or a control group (CON, n = 115, 2 schools, 5 classes). Before and after the 10-month intervention, resting heart rate and blood pressure measurements were performed as well as comprehensive transthoracic echocardiography and peripheral arterial tonometry (PAT). Analysis of baseline-to-10-months changes showed between-group differences ($P < 0.05$) after both training interventions in diastolic blood pressure (delta scores: SSG −2.1 ± 6.0 mm Hg; CST −3.0 ± 7.1 mm Hg; CON 0.2 ± 5.3 mm Hg). Moreover, there were between-group differences in delta scores ($P < 0.05$) in interventricular septum thickness (SSG 0.17 ± 0.87 mm; CST 0.30 ± 0.94 mm; CON −0.15 ± 0.68 mm), left-atrial volume index (SSG 0.32 ± 5.13 mL/m^2; CON 2.60 ± 5.94 mL/m^2), and tricuspid annular plane systolic excursion (SSG −0.4 ± 3.3 mm; CON: 0.1 ± 3.6 mm). No significant between-group differences were observed for the PAT-derived reactive hyperemia index. In conclusion, 10 months of 3 × 40 minutes per week of SSG and CST in 8- to 10-year-old children decreased diastolic blood pressure and elicited discrete cardiac adaptations, suggesting that intense physical exercise in school classes can have effects on cardiovascular health in children.

KEYWORDS
ball games, blood pressure, cardiac function, cardiac structure, echocardiography, football

1 | INTRODUCTION

Reductions in physical activity and cardiorespiratory fitness in children are associated with clustering of traditional cardiovascular risk factors, for example, obesity, increased blood pressure, and hypercholesterolemia that track into adult life and are linked to increased risk of cardiovascular disease.[1,2] Physical activity and participation in sport during childhood offer numerous benefits for physical, psychosocial, and cognitive health.[3,4] Current guidelines recommend that children should engage in at least 60 minutes or more of moderate to vigorous physical activity (MVPA) per day, and children with a higher average time engaged in MVPA have a more favorable cardiovascular risk factor profile regardless of the amount of sedentary time.[5,6] However, the proportion of children who are physically active is decreasing and data from the United States have showed that only 42% of children and 8% of adolescents engage in the recommended amount of MVPA, with data from Denmark indicating that in 11-year-old children, the figures are just 17% for boys and 7% for girls.[7,8]

While MVPA is the focus of available guidelines, specific characteristics of optimal physical training for children in various age groups have not been established. However, it is noteworthy that high-intensity interval training based on high-intensity aerobic bursts separated by recovery periods of lower intensity may be more effective than moderate continuous training for achieving improvement in cardiovascular risk factors and cardiac function in obese and non-obese children and adolescents.[9–11] Football, which is an intense, fun, social, and universally known team sport, has features of high-intensity interval training, and we have previously found considerable increases in aerobic fitness in 9- to 10-year-old schoolchildren after only 6 weeks of 2 × 30 minutes per week of intense football or unihockey training.[12]

School-based interventions are probably the most effective way to promote physical activity and fitness in children, and we also found significant structural and functional cardiac adaptations, as determined by echocardiography, in 9- to 10-year-old children after 10 weeks of 3 × 40 minutes per week of school-based small-sided football training.[13,14] In addition, we recently reported that, in children aged 10-12 years, 2 × 45 minutes of football training per week for 11 weeks had beneficial effects on blood pressure and body composition.[15] However, the cardiovascular effects of longer-term school-based football training compared to other types of physical training are unclear. Here, we report effects on fitness, traditional cardiovascular risk factors, echocardiographic variables, and vascular function after 10 months in children randomized to school-based small-sided football, circuit training, or a control group.

Please click on this video link to hear more about the study.

2 | METHODS

The study involved 291 8- to 10-year-old Danish third-grade schoolchildren from six different schools located in Copenhagen, the Danish capital, and Frederikssund, a rural city 35 km outside the capital. The participants were cluster-randomized to a small-sided games training group (SSG; n = 93, 4 schools, 5 classes), a circuit strength training group (CST; n = 83, 4 schools, 4 classes), or a control group (CON; n = 115, 2 schools, 5 classes). For each of the 2 years of the study, two rounds of cluster randomization were used to assign one control school and two training intervention schools per year, and to assign the active intervention schools to SSG or CST, with both training types represented at the four intervention schools. The control schools were instructed to maintain their normal curricular routines.

Baseline and post-intervention tests were performed during school time at the beginning and end of the school year by study staff members. Individual written informed consent was obtained from parents for all participants, and the children were informed about the purpose of the study and the testing procedures as well as their right (at any time and without requiring explanation) to say no to being tested. The study was approved by the Committees on Biomedical Research Ethics for the Capital Region of Denmark (J.no. H-3-2013-038) and formed part of the large-scale Frequent Intense Training – Football, Interval Running and Strength Training (FIT-FIRST) randomized controlled trial (Clinicaltrials.gov: NCT02000492).

2.1 | Training

The two different types of training session (SSG and CST) were performed at the schools' outdoor or indoor sports facilities during the last part of the day three times per week. No classes trained 3 days in a row.

The training was led by non-professional trainers normally involved in training at sports clubs but employed part-time by the university for this particular study.

Small-sided ball games involved various types of small-sided games, mainly football and less often basketball or floorball, on 20 × 13-m pitches. We aimed at 3v3 for all types of game. For practical reasons, other team and pitch sizes (eg, 4v4) were occasionally used, as well as other ball games (eg, team handball or volleyball). Each training session started with a 3- to 5-min warm-up with drills relevant to the ball game used in that particular session.

Circuit strength training was performed as approximately 30-second all-out exercise periods with 45-second rest periods in between, partly (around 50% of training sessions) conducted as traditional circuit training with 6-10 stations with plyometric and dynamic as well as static strength exercises using upper and lower body and body core, and partly using well-known games activating the children in the same way as traditional CST (eg, different catching games or stop dance).

Both types of training were performed outdoors when the weather allowed and mainly indoors during the winter.

Heart rate (HR) was recorded at 5-second intervals with Polar team system 2 HR monitors (Polar Electro Oy, Kempele, Finland) during at least two training sessions for each participant at the beginning, in the middle, and at the end of the intervention period, making sure that the reported training intensity reflected the intensity throughout the 10-month intervention. Mean HR was calculated together with HR distribution during training expressed as a percentage of the time spent at <70%, 70%-80%, 80%-90%, and 90%-100% of individual maximum heart rate (HR_{max}).

2.2 | Measurements

At baseline and after 10 months, the children were weighed wearing light clothing at the same time of day after at least 2 hours of fasting (Tanita WB-110MA, Tanita, Europe) and their height measured barefoot (235 Heightronic Digital Stadiometer; QuickMedical, Issaquah, WA, US), and they were clinically examined and interviewed by a medical doctor (CMN) who also assessed the Tanner stage of physical development. Tanner staging was based on observing the partly undressed child from the front and side, respectively, with visual evaluation of the size of the breasts or penis and of development of pubic hair, respectively. During the interview, the children were asked whether they participated in organized sporting activities at least once per week (yes or no) and for how long they were sedentary in front of a screen each day (<2, 2-4 or >4 hours). Fat mass index, (FMI) expressed as body fat mass divided by height squared, was estimated by a whole-body DXA scan (Lunar Prodigy; GE Medical Systems, Madison, Wisconsin, USA) using Encore software version 13.5 (Encore, Madison, USA). The children were scanned in a supine position wearing light clothing and instructed to fast for at least 2 hours before the scan.

Systolic and diastolic blood pressure (BP) and resting heart rate (HR) were measured after 10 min of rest in a quiet room with the participants lying on a transportable bed. BP and HR were recorded in the right upper arm using an automatic BP monitor (M6 HEM-7223-E, Omron, IL, USA) with a cuff adjusted to the arm size as appropriate. Three BP and HR measurements were taken, and the average used for further analysis. Mean arterial BP was calculated as 1/3 SBP + 2/3 DBP.[16]

Peripheral arterial tonometry (PAT) was performed with an EndoPAT2000 device (Itamar Medical Ltd., Caesare, Israel) and two finger-mounted pneumatic probes according to the manufacturer's instructions.[17] PAT has been established as a technically simple and reproducible technique for assessing endothelial function in adults and children that shows reasonable correlation ($r = 0.55$, $P < 0.0001$)[17] with measurement of brachial artery flow-mediated vasodilation (FMD) and has comparable value for predicting future adverse cardiovascular events in adults.[17–19] Digital pressure-wave oscillations were recorded continuously before, during, and after deflation of a blood pressure cuff on the non-dominant arm inflated to suprasystolic pressures for 5 minutes. Data were analyzed by the machine's computerized automated algorithm, and the reactive hyperemia index (RHI) was defined as the ratio of the average pulse-wave amplitude after 1 minute of reactive hyperemia divided by the average pulse-wave amplitude in the preocclusion baseline period normalized to the signal from the contralateral non-ischemic arm. HR was recorded at 1-second intervals throughout the whole period, and the lowest average value over a 30-second period was calculated. The lowest value from either this calculation or the BP measurements was registered as resting HR.

Transthoracic echocardiography was performed by the same experienced echocardiographer on a GE Vivid Q ultrasound machine (GE Medical System, Horten, Norway) with a 2.5-MHz transducer, as previously reported.[14,20] Offline analysis was performed using EchoPac BT08 software (GE Vingmed Ultrasound, Horten, Norway). In brief, left ventricular (LV) and right ventricular (RV) dimensions and interventricular septum thickness were measured in parasternal long-axis two-dimensional recordings according to current guidelines.[21] LV volumes and ejection fraction were calculated using Simpson's biplane method, and LV mass was calculated and indexed according to the body surface area using the DuBois formula.[22] Left atrium (LA) volume was also measured in apical projections using the biplane method and indexed for body surface area. Pulsed Doppler measurements of mitral inflow were performed in the apical four-chamber view to determine peak transmitral flows in early diastole (E) and during LA contraction (A), E/A ratio, deceleration time (DT) of early filling velocity curves, and global isovolumetric relaxation time (IVRT). RV systolic function was assessed by tricuspid annular plane systolic excursion (TAPSE) using M-mode echocardiography in the apical four-chamber view. Cardiac output (CO) was calculated using measurements of left ventricular outflow tract diameter and blood flow velocity, as previously described.[23] LV global longitudinal strain (global strain) was measured with two-dimensional speckle tracking, where LV deformation is determined by tracking speckles from frame to frame. In brief, after defining the time of closure of the aortic valve, three points were anchored inside the myocardium at the mitral valve plane and apically to allow for a semi-automated tracking algorithm to track all LV regions throughout the cardiac cycle. Apical images of the two-, three-, and four-chamber views of LV were divided into six segments, and the tracking quality of the total of 18 segments was manually approved or rejected, followed by automated calculation of a strain score for each apical view. To provide a measure for the entire LV, global strain was determined by the average of the three apical views to provide a measure for the entire LV.[14,20,24]

HR_{max} and aerobic fitness level were determined using the Yo-Yo intermittent recovery level 1 children's test (YYIR1C), which has been shown to be a reliable and valid test for determining HR_{max} and aerobic fitness level[25] in 6- to 10-year-olds. The test was carried out at the schools in indoor physical education facilities. The children were instructed to run 16 m back and forth in a straight lane marked by cones. The pace was set by beep signals and increased gradually during the test. Each shuttle run was followed by a 10-second period of active recovery around a cone placed 4 m behind the finishing line. One of the researchers participated in the test to guide the children and motivate them to reach exhaustion. During the test, HR was recorded at 1-second intervals using Polar team system 2 (Polar Electro Oy, Kempele, Finland) monitors. The highest HR value over 15 seconds was registered as HR_{max}.

2.3 | Statistics

Unless otherwise stated, data are presented as means ± SD. Baseline values for the three intervention groups (CON, SSG, and CST) were compared using one-way analysis of variance. To evaluate the intervention-induced effects, change (delta) scores from 0 to 10 months were compared for SSG vs CON and CST vs controls, respectively, using one-way analysis of variance. When the normality test failed (for all delta score comparisons), Kruskal-Wallis ANOVA on ranks was used. Between-group differences in training intensity were tested using an unpaired two-tailed Student's *t* test. SigmaPlot version 14.0 was used as the software package, and the significance level was set at 0.05.

3 | RESULTS

No baseline differences ($P > 0.05$) were observed between the three groups, except that systolic blood pressure was significantly lower in CST than in CON (100.4 ± 11.6 vs 104.5 ± 9.5 mm Hg), and more children spent 2-4 hours sitting in front of a screen in CST than in CON (32 vs 9%) (Table 1).

3.1 | Training intensity

Mean HR values as well as percentage of training time in HR zones (>70%HR_{max}, 70%-80%, 80%-90%, 90%-95% and 95%-100%) are presented in Figure 1.

TABLE 1 Study group characteristics before (pre) and after (post) the 10-month intervention period

	CON				SSG				CST			
	Pre		Post		Pre		Post		Pre		Post	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (y)	9.3	0.3	10.0	0.3	9.3	0.4	10.0	0.4	9.3	0.3	10.0	0.3
Weight (kg)	32.8	6.1	35.2	6.8	32.7	7.1	35.4	7.7	32.2	7.1	35.3 *	7.6
Height (cm)	138.4	6.1	142.4	6.4	138.2	6.8	142.4	7.3	136.9	5.7	141.1 *	5.9
FMI (kg/m)	4.0	2.1	4.2	2.2	4.1	2.3	4.3	2.3	4.2	2.3	4.5	2.4
Systolic BP (mm Hg)	104.5	9.4	105.6	9.7	104.5	10.0	103.1	8.6	100.4 **	11.6	102.7	8.7
Diastolic BP (mm Hg)	61.2	7.8	61.4	7.9	61.2	5.6	59.1*	4.4	60.6	6.5	57.6 *	5.1
MAP (mm Hg)	75.7	6.5	76.1	6.4	75.6	6.5	73.8	5.1	73.9	7.6	72.7	5.4
RHR (bpm)	72.0	9.6	71.9	8.7	72.1	8.5	70.4	7.8	70.9	9.2	70.7	10.3
RHI	1.30	0.39	1.43	0.48	1.21	0.37	1.31	0.37	1.20	0.28	1.30	0.43
YYIR1C (m)	719	413	847	448	759	463	909	490	681	377	805	439
Tanner stage (1/2/3) %	85/13/2		78/22/0		87/13/0		78/22/0		94/6/0		76/24/0	
Sports club active	60%				72%				72%			
Screen time (<2/2-4/>4 h/d) %	91/9/0				79/21/0				68/32/0			

Data are presented as means ± SD, except for Tanner stage distribution (% in stages 1/2/3, respectively).

SSG, small-sided games; CST, circuit strength training; CON, control group; FMI, fat mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; RHR, resting heart rate; RHI, reactive hyperemia index; YYIR1C, Yo-Yo intermittent recovery level 1 children's test.

*$P < 0.05$ for comparison of delta values of respective parameters between pre and post in the intervention groups compared to the control group.

**$P < 0.05$ for differences in baseline (pre) values.

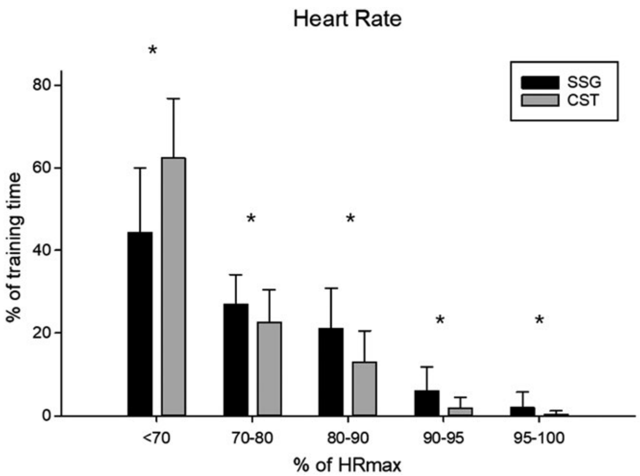

FIGURE 1 Time spent (% of training time) in various heart rate zones in percentages of maximum heart rate (HR_{max}) during low-volume small-sided games (SSG, black bars) and circuit strength training (CST, grey bars). Data are presented as means ± SD. *Denotes $P < 0.05$ for differences between SSG and CST

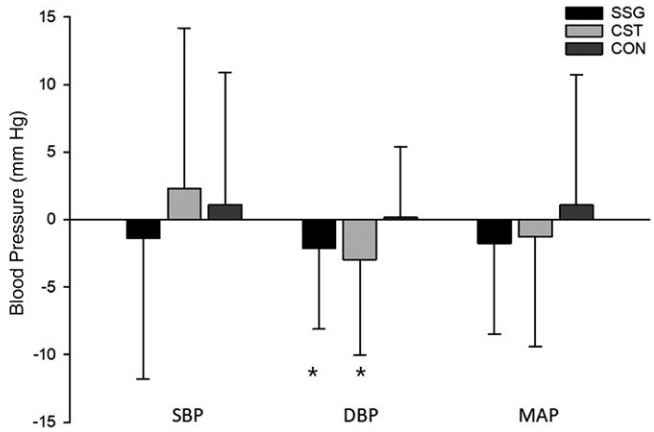

FIGURE 2 Changes in blood pressure (mm Hg) after 10 months of small-sided games (SSG, black bars), circuit strength training (CST, light grey bars), or in controls (CON, dark grey bars). Data are means ± SD. *$P < 0.05$ for delta scores compared to CON. SBP, systolic blood pressure; DBP, diastolic blood pressure; MBP, mean arterial pressure

3.2 | Blood pressure, resting heart rate, aerobic fitness, and endothelial function

Analysis of baseline-to-10-months changes showed between-group differences in diastolic blood pressure, which was lowered more in both training intervention groups than in the control group (SSG −2.1 ± 6.0 mm Hg; CST −3.0 ± 7.1 mm Hg; CON 0.2 ± 5.3 mm Hg, $P < 0.05$), whereas no significant between-group differences in delta scores after the 10-month intervention period were seen in aerobic fitness, resting heart rate, and systolic blood pressure (Figure 2). Also, changes in RHI measured by PAT were not significantly different between the study groups (Table 1).

3.3 | Cardiac structure and function

Analysis of baseline-to-10-months delta scores showed between-group differences indicating an increase in interventricular septum thickness in both training groups compared to the control group (SSG 0.17 ± 0.87 mm; CST 0.30 ± 0.94 mm; CON −0.15 ± 0.68 mm, $P < 0.05$). No significant between-group differences in delta scores were seen in the other examined geometric echocardiographic variables after the 10-month intervention period, including LV diastolic and systolic diameters, LV posterior wall diameter, and LV mass index (Table 2).

Between-group differences ($P < 0.05$) were also observed in SSG compared to CON in LA volume index (delta scores: SSG 0.32 ± 5.13 mL/m^2; CON 2.60 ± 5.94 mL/m^2) and TAPSE (SSG −0.4 ± 3.3 mm; CON: 0.1 ± 3.6 mm).

No significant between-group differences in change scores after the 10-month intervention period were seen in the examined measures related to LV diastolic function, that is, E, A, E/A ratio, IVRT and DT, or in global strain (Table 2).

4 | DISCUSSION

The primary results of the present study were that a 10-month school-based intervention consisting of either small-sided ball games or circuit strength training elicited cardiovascular adaptations in 9- to 10-year-old children, including lowered diastolic BP and discrete cardiac adaptations. High HRs were elicited during the three times weekly 40-minute training sessions, especially with the SSG (football) intervention, whereas no significant between-group differences were observed in endothelial function measured by PAT.

Blood pressure tracks from childhood to adulthood, that is, children with higher BPs are more likely to become hypertensive adults, and the observed decrease in diastolic BP in SSG and CST is an important finding as in normotensive children, no clear link has been established between physical activity and blood pressure.[26,27] However, a reduction in diastolic, but not systolic, BP was also observed after a 14-week school-based exercise intervention in 10-year-old normotensive South African children,[28] and in a recent study, we found a decrease in systolic, but not diastolic, BP in 10- to 12-year-old normotensive children after an 11-week intervention involving small-sided football.[15] Moreover, a study of 9- to 11-year-old children found that both SBP and DBP decreased in a hypertensive group as well as in a group with normal blood pressure after 8 months of three extra school-based PE lessons per week.[29] The current sum of evidence therefore suggests that school-based high-intensity physical

TABLE 2 Echocardiographic variables before (pre) and after (post) the 10-month intervention period

	CON				SSG				CST			
	Pre		Post		Pre		Post		Pre		Post	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
LVDD (mm)	40.0	3.30	41.4	2.9	40.2	2.9	40.9	3.2	39.5	3.6	40.1	3.4
LVSD (mm)	24.1	3.2	25.1	3.0	24.4	2.7	25.4	2.8	23.5	3.50	24.6	2.8
LVPW (mm)	6.46	0.72	6.53	0.74	6.33	0.97	6.27	0.93	6.27	0.82	6.51	0.70
IVS (mm)	6.31	0.76	6.15	0.66	6.13	0.82	6.31 *	0.72	6.15	0.84	6.46 *	0.80
CO (l/min)	2.97	0.65	2.84	0.66	2.83	0.61	2.74	0.62	2.77	0.98	2.73	0.82
RVDD (mm)	18.2	2.4	18.1	2.3	17.6	2.4	17.8	2.5	18.3	2.6	18.5	2.7
TAPSE (mm)	18.7	3.1	19.8	3.3	19.6	3.3	19.2*	3.0	19.4	3.3	19.3	3.1
E (m/s)	1.04	0.15	1.06	0.13	1.01	0.17	1.03	0.14	0.99	0.16	1.02	0.15
A (m/s)	0.50	0.11	0.46	0.10	0.46	0.11	0.47	0.11	0.47	0.11	0.46	0.12
E/A	2.19	0.65	2.45	0.71	2.29	0.61	2.32	0.58	2.21	0.67	2.36	0.70
IVRT (ms)	60.2	5.9	60.9	6.3	60.2	6.0	62.2	6.5	59.8	6.6	60.5	7.1
LA volume index (mL/m^2)	21.3	5.6	24.0	5.6	22.2	5.0	22.5 *	5.1	21.7	5.5	22.9	5.8
DT time (ms)	160.7	26.9	162.3	25.6	155.1	24.7	157.8	23.9	163.1	32.7	161.1	27.6
Ejection Fraction (%)	55.7	5.7	54.5	5.7	55.3	6.00	55.8	5.9	56.0	6.7	54.9	5.3
Global strain (%)	−21.0	2.3	−21.0	1.9	−21.2	1.7	−21.2	2.1	−21.0	2.2	−21.1	2.2
LV mass index (g/m^2)	64.5	13.3	65.4	11.4	63.7	13.4	63.3	12.6	61.0	12.5	64.5	12.6

SSG, small-sided games; CST, circuit strength training; CON, control group; LVDD, left-ventricular diastolic diameter; LVSD, left ventricular systolic diameter; LVPWD, left ventricular posterior wall diameter; IVS, interventricular septum thickness; CO, cardiac output; RVDD, right-ventricular diastolic diameter; TAPSE, tricuspid annular plane systolic excursion; E, peak transmitral flow velocity in early diastole; A, peak transmitral flow velocity during atrial contraction; $IVRT_{global}$, global isovolumetric relaxation time; LA, left-atrial; DT, transmitral deceleration time; EF, ejection fraction; LV, left ventricular.

Data are presented as means ± SD.

*$P < 0.05$ for delta values of respective parameters between baseline (0 weeks) and 10 mo in the intervention groups compared to the control group.

training is feasible for reducing BP in normotensive children, and the potential of such interventions for primary prevention of hypertension and cardiovascular death clearly warrants further study.

We found that interventricular septum thickness increased significantly more after both training interventions compared to the control group. This aligns with preliminary findings previously reported in a subgroup of the current SSG study population that was examined after 10 weeks.[14] At that earlier point in time, however, the significant score change for left-atrial volume index now reported after 10 months was not apparent. It is well-established that obese children display structural and functional cardiac abnormalities, including increased LA and LV dimensions, increased LV mass, and diastolic and systolic LV, and RV dysfunction, respectively that track into adulthood and can be improved by weight loss interventions.[30] In overweight children, it is possible that high-intensity interval training is more effective than moderate-intensity training for achieving favorable cardiac changes and amelioration of cardiovascular risk factors, for example, maximal oxygen uptake, BP, and endothelial dysfunction.[8,9,30] Indeed, in a previous non-randomized pilot trial, we found improvement in RV function measured by TAPSE in overweight children after 3 months of football training,[20] whereas in the present study, we found a slight increase in TAPSE in CON vs SSG. This seeming paradox (as well as the apparent decrease in LA volume index in CON vs SSG) may be a spurious finding resulting from multiple testing. We are not aware of other reports examining the effects of football and other training modalities on echocardiographic variables in healthy, non-obese children. Depending on the examined age group, the results will, of course, invariably integrate the effects of normal cardiac development and concurrent physiological changes, for example, in body surface area and maturity stage.

We did not find significant between-group score changes in endothelial function determined by PAT-derived RHI. Endothelial function assessed by FMD or PAT is reduced in children with obesity, type 1 diabetes, and other risk factors for cardiovascular disease, and these measures may be correlated with the level of physical activity in normal-weight children and adolescents.[30–34] Whether physical training can improve endothelial function in unselected healthy children remains to be determined. Importantly, although assessments of endothelial function by FMD and PAT are correlated, these modalities reflect large conduit artery and microvascular endothelial function, respectively, and relations between responses (at least in adults) of the respective arterial segments and the presence of cardiovascular risk factors may differ.[35] It is possible that the RHI of the children participating in our study was too good to be improved by the intervention. Moreover, studies suggest that microvascular function matures with age in healthy children, and in children aged 10-16 years, pubertal status is the main predictor of RHI, with a positive correlation between Tanner stages and RHI.[36] In the current 10-month study of children aged 9-10 years, Tanner stages increased in all study groups, and whether this development or other subtler biological maturation effects contributed to the absence of between-group score changes in RHI requires further study. Also, the Tanner stage is not a very sensitive index of maturity status.

It is somewhat surprising that the SSG and CST training interventions, despite long periods with high HRs, did not lead to significant changes in YYIR1C performance compared to the control group. Indeed, we have previously found increased YYIR1C performance indicative of augmented aerobic fitness after only 6 weeks of school-based training with small-sided ball games in 8- 9-year-old children with a volume of only 2×30 min/wk and similar $HR_{mean.}$[12] Compared to that study, the absolute changes from baseline to 10 months observed in the present study were very similar (137 vs 151 m). Increased aerobic fitness has also been observed after continuous or interval training in other studies of healthy children.[10] Studies investigating effects on aerobic fitness after strength training in children are limited, but enhanced performance on a half-mile run has been found after participation in plyometric training, a form of training based on jumping exercises that elicited HR_{max} of 188 ± 3.5 bpm.[31] In the current study, HR during CST was significantly lower than during SSG, as also shown in an earlier report where lower volumes of 3v3 soccer, unihockey, and basketball elicited even higher HRs than observed in small-sided games representative of SSG.[12] Indeed, this may have contributed to the absence of enhanced aerobic fitness as assessed by YYIR1C performance in SSG and CST compared to CON in the present study, despite higher training volumes. Also, the study participants were physically active at baseline, with a majority being active in sports clubs at least once per week and only a few staying sedentary in front of a screen for 2-4 hours per day (Table 1), which may have contributed to the absence of an increase in fitness during the study period.

While the study is strengthened by the randomized design and 10-month controlled intervention period, it is limited by the lack of knowledge about the physical activity patterns (eg, by actigraphy data) of all study groups during and outside school. For example, one study reported that children who were more active during the school day in sports schools were less active during their leisure time compared to children attending normal schools[37]. Another limitation is that the clinical relevance of the findings is as yet unknown.

In conclusion, 10 months of 3×40 minutes per week of SSG and CST in 8- 10-year-old children decreased diastolic blood pressure and elicited discrete cardiac adaptations, suggesting that intense physical exercise in school classes can have effects on cardiovascular health in children.

5 | PERSPECTIVES

The present study indicates that a 10-month (full school year) school-based training intervention comprising either SSG or CST can elicit cardiovascular adaptations in healthy 8- 10-year-old children. The FIT FIRST concept involves frequent sessions with high-intensity sports-based activities deploying modified rules that suit the school setting. The results of the current study and other related work emphasize that frequent 40-minute sessions of football, basketball, and floorball, small-sided drills, and games, as well as circuit strength training, can be effective for improving cardiovascular health. More studies involving long-term school-based high-intensity physical exercise programs to investigate mental and physiological health effects with clinical endpoints are warranted.

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CONFLICTS OF INTEREST

None declared.

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